Grasping the Complexity of Information Systems Development Projects:

A Taxonomy and Assessment

by

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The complexity of information systems development projects (ISDPs) can be understood and measured along two dimensions: organizational versus technological, and structural versus dynamic. The results of this study suggest that when it comes to the complexity of ISDPs, the technological aspects are more visible, but the organizational aspects are more important in affecting ISDP performance. In order to improve project performance, companies must effectively manage the organizational as well as the technological aspects of their ISDPs.

Projects are the basic unit by which contemporary organizations manage their information systems (IS) development activities. Historically, IS projects have been known for a notoriously high failure rate [5]. For example, the Standish Group reported that US companies spent more than $250 billion each year in the early 1990s on IS projects, with only 16.2 percent considered successful [9]. The Standish Group's 2001 report [10] found that, although US companies invested four times more money in IS projects in 2000 than they did annually in the 1990s, only 28 percent could be considered successful. The results suggest that, although much improved, the success rate of IS projects was still very low. As a result, a significant amount of money has been wasted on failed IS projects. Therefore, there is a strong economic incentive for companies to improve IT project performance.

In this article, IS development refers to the analysis, design and implementation of IS applications/systems to support business in an organizational context. ISDPs include work on new applications/systems yet to be installed, as well as enhancement of existing

applications/systems. New applications/systems include both in-house application/systems and off-shelf packaged software.

One reason that IS projects fail is that they are too complex [7]. ISDPs are inherently complex because they must deal with not only technological issues but also organizational factors that by and large are outside of the project team's control. In addition, both information technologies and business environments are changing at an unprecedented rate, making business requirements and technical specifications of the ISDP increasingly uncertain and difficult to manage. IS organizations are under increasing pressure to do more with less resources and to deliver systems under shorter development lifecycles [12]. Rapid technological changes and tougher business demands make ISDPs even more complex, exacerbating the problems with poor ISDP performance [3]. However, IS organizations have displayed great difficulty in coping with the progressively increasing ISDP complexity. To improve success rate and return on investment, it is critical that organizations are able to develop strategies to effectively manage the complexity of IS projects.

Before we can develop effective strategies to control and manage ISDP complexity, it is necessary that we understand the project characteristics that constitute ISDP complexity and are able to use those characteristics to assess the complexity of an ISDP. In addition, the significant effects of ISDP complexity on project performance need to be understood to convince top management of the importance of managing ISDP complexity. Since both ISDP complexity and project performance are multi-dimensional, it is also crucial that we understand how the various ISDP complexity components affect the different project performance measures. Such an understanding will help ISDP managers focus on those complexity components that have the

most significant impacts on project success measures that are of the most importance to the company.

In this article, built on previous research literatures and based on insights gained through interviews with ISDP managers, we propose a taxonomy that describes the key dimensions and components of ISDP complexity. Based on this taxonomy, we collected survey data of 541 ISDPs to empirically develop a measurement for assessing ISDP complexity. We then analyzed the ISDPs in the sample to provide additional insights about the impacts of ISDP complexity on project performance. Key questions addressed in the article include:

1. *What are the key components of ISDP complexity?*
2. *Does ISDP complexity, if we can measure it, really affect project performance?*
3. *Do the various components of ISDP complexity affect project performance equally? If not, how do they differ?*

Taxonomy of ISDP Complexity

Both researchers and practitioners frequently use the term ISDP complexity in their writings and practices. However, to our knowledge, there exist no well-defined frameworks in the literature that can be used to systematically describe the key dimensions and characteristics of ISDP complexity. There is also a lack of commonly accepted measurements that can be used to assess the complexity of an ISDP. By building on the literatures and incorporating insights from ISDP managers, in this article, we make the first step to develop such a framework and measurement tool and to provide initial empirical evidence of the negative effects of ISDP complexity on project performance. Two literatures sources, the general project management literature on project complexity and the IS literature on software project risk factors, are of particular relevance and are thus used as the bases for developing our taxonomy and measures.

In project management literature, a number of project dimensions and characteristics have been identified as constituents of project complexity. Based on a literature review, Baccarini [1] defines project complexity in terms of the number of varied elements and the interdependency between these elements. Applying this concept, he defines two types of project complexity: organizational complexity (the number of and relationships between hierarchical levels, formal organizational units, and specializations) and technological complexity (number of and relationships between of inputs, outputs, tasks, or technologies). Turner and Cochrane [11] raise another dimension of complexity: uncertainty in project goals and in the means for achieving those goals. Uncertainty in this case refers to the extent to which the project goals and means are ill defined and are thus subject to future changes. Uncertainty in systems requirements/scope and uncertainty in new information technologies are examples of goal and mean uncertainties. By integrating the dimensions proposed by Baccarini [1] and Turner and Cochrane [11], Williams [12] defines two distinct aspects of project complexity: structural complexity (underlying structure of the project) and uncertainty-based complexity (the uncertain or changing nature of the project). He contends that uncertainty adds to the complexity of a project and can be viewed as a constituent dimension of project complexity.

In IS literature, the software project risk factor literature provides a useful basis for developing our framework and measures. Software project risk has been defined as an uncertainty condition that can present a serious threat to the successful completion of a software development project [8]. In essence, the components of ISDP complexity can be viewed as drivers of many project risks. The importance of software project risk can be understood in terms of "some combination of risk frequency (that is, how likely it is that the risk will occur) and risk impact (such as, how serious a threat the risk represents if it does occur)" ([6], p.79).

Most of the software project risk studies have focused on identifying lists of such risk factors (e.g., [4]), without developing a deeper understanding of measurement and impacts of the various risk factors. Nevertheless, the IS software project risk factor literature provides an important basis for addressing the dynamic or uncertainty-based aspect of ISDP complexity. In addition, it provides a rich source for developing measures of ISDP complexity. In general, we can classify the common risk factors either as organizational or technological. For example, among the top 11 risk factors that Keil and his colleague [6] identified, one risk factor was related to information technology and the rest all related to the organizational aspects of the software project risks.

In our study, in addition to the literature review, we also conducted interviews and focus group discussions with 74 IS project managers to gain additional insights and to refine the dimensions and characteristics of ISDP complexity. Based on the literatures and the insights, we propose a taxonomy of ISDP complexity that is composed of two dimensions: organizational versus IT, and structural versus dynamic (shown in Figure 1). Consistent with Baccarini [1] and Keil et al. [6], we can view ISDP complexity from either the organizational or the technological aspects of the project. Drawing upon Turner and Cochrane [11] and Williams [12], we can assess both the organizational and the technological aspects of ISDP complexity, in terms of either the structural complexity among the current project components or the dynamic/uncertain nature resulting from the potential changes that may occur. In this taxonomy, each dimension suggests two distinct aspects of ISDP complexity rather than a continuum-based variable.

Insert Figure 1 about here

The proposed taxonomy defines ISDP complexity as consisting of four components: S*tructural Organizational Complexity* (Structural_Org), *Structural IT Complexity* (Structural_IT), *Dynamic Organizational Complexity* (Dynamic_Org), and *Dynamic IT Complexity* (Dynamic_IT). The Structural_Org component reflects the nature and the strength of the relationships between the project elements and the organizational supporting environment, e.g., project resources, support from top management and users, project staffing, and the skill proficiency levels of the project personnel. The Structural_IT component captures the coordinative complexity among the IT elements, reflecting the diversity of user units, software environments, nature of data processing, variety of technology platform, need for integration, and the diversity of external vendors and contractors. The Dynamic_Org component captures the pattern and rate of changes in the ISDP organizational environments, including changes in user information needs, business processes, and organizational structures. It also reflects the dynamic nature of the project's impact on the organizational environment. The Dynamic_IT component measures the pattern and rate of changes in the IT environment of the ISDP, including changes in IT infrastructure, architecture and software development tools.

Measurement and Assessment of ISDP Complexity

Using a rigorous instrument development process, we developed a measurement of ISDP complexity. The empirical data for the study was collected using a web-based online survey of 541 ISDPs. The process and methods used in the study are discussed in the methodology sidebar. Table 1 presents the measurement list for the four ISDP complexity components and the mean scores corresponding to each measure from the sample of 541 ISDPs. All measures of ISDP complexity were assessed using a seven-point scale, where a higher number indicates a higher level of complexity.

Insert Table 1 about here

Figure 2 illustrates the mean scores of the four dimensions of ISDP complexity as assessed by the project managers in the sample. The Structural_IT component had the highest complexity score, followed by the Dynamic_Org, Structural_Org, and Dynamic_IT components. When it comes to IT complexity, ISDP managers in the study sample perceived structural complexity to be higher than dynamic complexity. In contrast, with respect to organizational complexity, dynamic complexity was ranked higher than structural complexity. As shown in Table 1, the scores of the measures for the Structural_IT component were relatively higher than those for the other complexity components, indicating that Structural_IT complexity was more visible to the ISDP managers than the other components.

Insert Figure 2 about here

Impacts of ISDP Complexity on Project Performance

Although it has been widely recognized that ISDP complexity causes poor project performance, little empirical evidence has been produced. Using the measurement of the ISDP complexity, in this study, we first examined the relationship between the overall ISDP complexity and project performance. We then analyzed the different effects of the four ISDP components on project performance. ISDP performance was captured using four widely used measures: project delivery time, cost, system functionality, and end-user satisfaction.

A correlation analysis of the 541 ISDPs suggests that overall ISDP complexity was negatively associated with all four measures of project performance. Higher ISDP complexity

was associated with delayed project delivery, cost overrun, reduced system functionality, and lower end-user satisfaction. To further explore the pattern through which the four ISDP complexity components affect project performance, we employed regression analysis to compute the effects of the four complexity components on the four measures of project performance. As shown in Figure 3, the results suggest that the four ISDP complexity components indeed had different effects on project performance. Structural_Org seemed to be the most critical complexity component that directly affected all four measures of project performance. Among the four performance measures, the Structural_Org complexity had the highest impact on end-user satisfaction, followed by project delivery time, system functionality, and cost.

Insert Figure 3 about here

The Dynamic_Org complexity component negatively affected project cost performance, indicating that changes in organizational structure and business processes might cause project scope changes, which in turn, cause cost overrun. The Dynamic_IT complexity influenced only system functionality. One plausible explanation is that changes in IT infrastructure, architecture, and software development tools might cause interruptions in the technical foundations and tools that are critical to the ISDP, which might make it difficult to meet the initial system functionality requirements, and then affect the delivery of the required system functionality. The Structural_IT complexity component, however, did not have a significant and direct impact on any of the project performance measures.

From a project performance point of view, end-user satisfaction and project delivery time were primarily influenced by the Structural_Org complexity. Project cost performance was most

affected by the Structural_Org complexity and the Dynamic_Org component, whereas system functionality was mostly impacted by Structural_Org and Dynamic_IT complexity.

Implications and Conclusions

Using a systematic approach involving extensive literature review, interviews and focus group discussions with ISDP managers and a survey of 541 ISDPs, we developed a taxonomy and measurement of ISDP complexity, and tested the relationships between ISDP complexity and project performance. The taxonomy is composed of two dimensions of ISDP complexity, technological versus organizational, and structural versus dynamic, which in turn define four components of ISDP complexity. As the first step towards understanding and coping with ISDP complexity, we developed the taxonomy in an attempt to answer the question of what constitute ISDP complexity. The taxonomy highlights the multi-dimensional nature of ISDP complexity, and can be used to serve as a useful conceptual tool for defining and communicating ISDP complexity. The measurement developed in this study can be used as a starting tool to assess and manage the various aspects of ISDP complexity. Without measurement, it is difficult for companies to collect baseline data about ISDP complexity, identify areas of concerns, and develop effective strategies to cope with particular problems. A measurement tool also allows organizations to track over time project complexity level, organizational techniques used to deal with different components of ISDP complexity, and project performance. Such data will enable organizations to establish knowledge bases that can be used for planning and controlling future ISDPs.

The study provides empirical evidence of the negative impact of ISDP complexity on project performance. The results suggest that a higher level of ISDP complexity is associated with project delays, cost overruns, reduced system functionality, and lower user satisfaction. In

addition, the results suggest that the four components of ISDP complexity have different effects on project performance. The structural organizational aspects of ISDP complexity have the most negative impacts on all four measures of project performance. This finding is consistent with Keill et al. [6] who found that 10 out of 11 top software project risk factors are organizational in nature.

One of the most interesting findings of the study is that Structural_Org had relatively stronger impacts on all four measures of project performance than the other three complexity components. To improve ISDP performance, organizations therefore need to pay close attention to the organizational aspects in addition to the technological aspects of their ISDPs. In particular, project managers need to develop strong relationships with top management and end-users. It is critical that the project is assigned qualified personnel with required knowledge and skills. Another interesting finding from this study is that although the ISPD managers in the sample perceived the structural technological complexity of ISDP to have the highest complexity scores, once the effects of the structural organizational complexity component were controlled, they did not significantly affect ISDP performance. This finding suggests that although the technological aspects of ISDP complexity were most visible to the project managers, they might not have the most significant impact on project performance, largely due to the organization's technological maturity. As suggested by Keil and his colleagues [6], although IT poses complexity and risks to the project, they may not significantly affect project performance because IT complexity and risks are largely within the control of the project. Understanding the different impacts of the four ISDP complexity components allows project managers to more effectively utilize the limited resources by focusing on the most influential ISDP complexity components.

The results of this study also provide some interesting insights on how a particular measure of project performance is affected by the various components of ISDP complexity. If the organization's emphasis is project on-time delivery and user satisfaction, project managers need pay more attention to the structural organizational factors. If project cost is the focus, project managers should focus on not only the structural organizational factors but also changes in the organizational environment. On the other hand, if system functionality represents the highest priority, project managers need to attend to both the structural organizational factors and the changes in the technology environments. This insight may help managers to focus on the most critical complexity components based on the specific performance measures that need to be improved.

This study represents the first step toward developing frameworks and measures for better understanding and managing ISDP. Built on this study, future research may investigate the organizational factors that influence ISDP complexity. Organizations can then control the complexity level of their ISDPs and therefore enhance the ISDP success rate, by creating effective strategies, methods, and coping mechanisms to control and manage those organizational factors that influence ISDP complexity.

Methodology Sidebar: How the study was conducted

We used a four-phase research process to develop and validate the taxonomy and measures of ISDP complexity. In the conceptualization phase, we proposed and refined the taxonomy based on extensive literature reviews and interview discussions with six ISDP managers. In the measurement development phase, we generated an initial pool of ISDP complexity measures by adapting relevant measures from the literatures, and by conducting

interviews and focused group discussion with 45 ISDP managers. We tested and modified the initial items using sorting procedures with four ISDP managers, and a pilot test with four ISDP managers and three IS researchers. We created and pilot-tested a web-based questionnaire with 15 ISDP managers.

In the large-scale data collection phase, the *Information Systems Special Interest Group* of the *Project Management Institute* (PMI-ISSIG) sponsored and provided member access for our web-based survey. Seven-point scales were used for items measuring ISDP complexity. We used two criteria to select appropriate respondents: (1) North American PMI-ISSIG members who (2) are project managers (not specialists such as programmer or systems analysts), and (3) managed a recently completed ISDP within 3 years. The reason for choosing North American members was to avoid bias and problems that may be caused by language barriers that the non-English speaking members in the other regions may have.

Overall 541 usable responses were gathered, representing a response rate of 31.1%. The respondents' organizations represented a variety of industries, including manufacturing (13.7%), finance/insurance (20.6%), retailing (5.3%), consulting (6.3%), healthcare (5.9%), software (9.7%), transportation (4.0%), government (9.2%), and utility (7.4%). The median annual sales of the companies were $800 million. The sample represented three types of ISDPs: in-house software development (38.1%), packaged software implementation (33.9%) and major enhancement of existing software (28%). The median project budget was $550,000 with the median project duration of 9 months. Since the sample represented a broad range of companies and projects, we believe that it is unlikely that the study results would be biased by the sample.

In the measurement validation and data analysis phase, to test the construct validity of the measures, we conducted factor analysis with varimax rotation. Four factors with eigen values

greater than one emerged from the analysis, which can be interpreted as corresponding to the four components of the ISDP complexity. All items loaded onto their intended factors. The results of factor analysis on the project performance measures also indicated adequate construct validity. We used Crobach's alpha as an indicator of the reliability of the measures. The Crobach's alpha coefficients of the ISDP complexity components and of the project performance measures were Structural_Org (0.71), Structural_IT (0.78), Dynamic_Org (0.81), Dynamic_IT (0.90), and performance (0.90), all greater than the recommended 0.70 for this type of research. The test results suggest that the measures demonstrated adequate validity and reliability. The final measures for the four components of ISDP complexity are presented in Table 1.

REFERENCES

1. Baccarini, D. The concept of project complexity-a review. *International Journal of Project Management 14, 4* (1996), 201-204.
2. Barki, H., Rivard, S. and Talbot, J. An integrative contingency model of software project risk management. Journal of Management Information Systems 17, 4 (2001), 37-69.
3. Benamati, J. and Lederer, A.L. Coping with rapid changes in IT. *Communication of the ACM 44, 8* (2001), 83-88.
4. Boehm, B.W. Software risk management: principles and practices. *IEEE Software 8*, *1* (January 1991), 32-41.
5. Johnson, J. Chaos: the dollar drain of IT project failures. Application Development Trends 2, 1 (January 1995), 41-47.
6. Keil, M., Cule, P.E., Lyytinen, K. and Schmidt, R.C. A framework for identifying software project risks. *Communications of the ACM* 41, 11 (1998), 76-83.

7. Murray, J.P. Reducing IT project complexity. *Information Strategy: The Executive's Journal 16, 3* (Spring 2000), 30-38.
8. Schmidt, R., Lyytinen, K., Keil, M., and Cule, P. Identifying software project risks: an international Delphi study. *Journal of Management Information Systems 17, 4* (2001), 5-36.
9. The Standish Group. *The Chaos Report.* (1994).
10. The Standish Group. *The Chaos Report.* (2001).
11. Turner, J.R. and Cochrane, R.A. Goals-and-methods matrix: Copying with projects with ill defined goals and/or methods of achieving them. *International Journal of Project Management*, 11, (1993), 93-102.
12. Williams, T.M. The need for new paradigms for complex projects. *International Journal of Project Management 17, 5* (1999), 269-273.

Organizational vs.	Structural Organizational Complexity (Structural_Org)	Dynamic Organizational Complexity (Dynamic_Org)
Technological	Structural IT Complexity (Structural_IT)	Dynamic IT Complexity (Dynamic_IT)

Structural vs. Dynamic

Figure 1. Taxonomy of ISDP complexity

Table 1. Measures and mean scores of ISDP complexity (n=541)

ISDP Complexity Components and Measures	Mean
Structural organizational complexity (Structural_Org)	
- The project manager didn't have direct control over project resources	4.03
- Users provided insufficient support	3.54
- Insufficient staffing for the project	3.24
- Project personnel did not have required knowledge/skills	3.22
- Insufficient support from top management	2.97
Structural IT complexity (Structural_IT)	
- The project involved multiple user units	5.63
- The project team was cross-functional	5.39
- The project involved multiple software environments	5.26
- The system involved real-time data processing	5.17
- The project involved multiple technology platforms	5.01
- The project involved significant integration with other systems	4.99
- The project involved multiple contractors and vendors	3.77
Dynamic organizational complexity (Dynamic_Org)	
- The project caused changes in business processes	5.57
- Users' information needs changed rapidly	3.93
- Users' business processes changed rapidly	3.78
- The project caused changes in organizational structure	3.31
- Organizational structure changed rapidly	2.96
Dynamic IT complexity (Dynamic_IT)	
- IT infrastructure changed rapidly	3.28
- IT architecture changed rapidly	3.17
- Software development tools changed rapidly	2.82

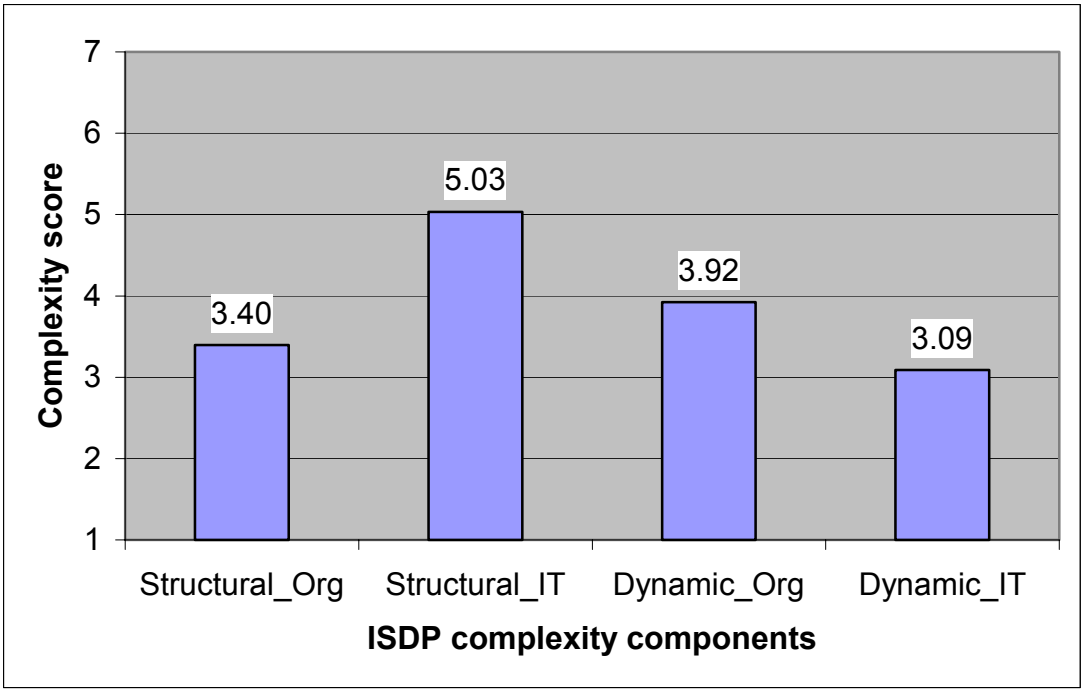

Figure 2. Mean Scores of the four components of ISDP complexity

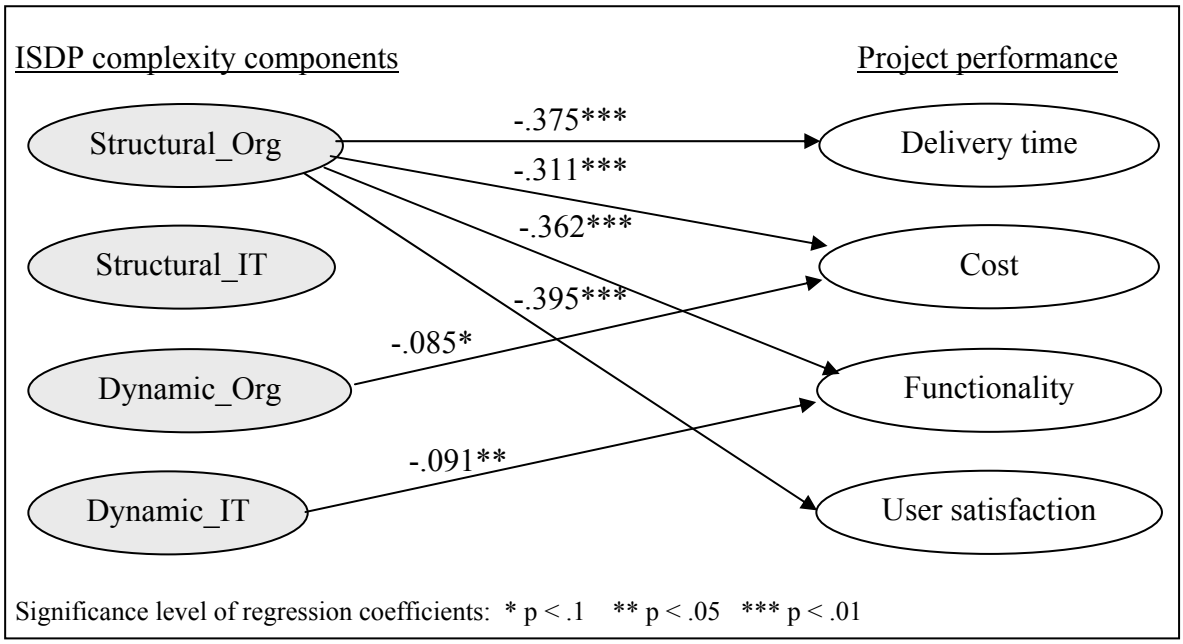

Figure 3. Impacts of ISDP complexity components on project performance measures